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Fast, High Power Microwave Components Based on Beam Generated Plasmas

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It is shown that the agile mirror plasma, under development as a device to simply and cheaply give electronic steering to microwave beams, also has application as a fast, electronically controlled, high power reflector or phase shifter. In a radar system, this can lead to such applications as pulse to pulse polarization agility and electronic control of antenna gain, as well as to innovative approaches to high power millimeter wave circulators.

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FAST, HIGH POWER MICROWAVE COMPONENTS BASED ON BEAM GENERATED PLASMAS

1. Introduction

Recent work at NRL has investigated the properties of a plasma called the agile mirror[1-4]. This is a planar plasma which reflects microwaves like a metal plate, but which can be repositioned electronically, so that a radar or communication system, can have electronic beam steering, similar to a phased array. While not as capable as a full phased array, the agile mirror has the potential of being simpler, lighter and cheaper. As such, it is of potential interest to the Navy. So far, experimental research on the agile mirror has shown that it is a beam generated plasma, which is a high quality microwave reflector at X-Band. The beam is confined by a magnetic field of typically 100 to a few hundred Gauss, and the plasma is turned on or off on a time scale of several tens of microseconds. It is a high quality reflector in the sense that the plasma mirror does not spread out the frequency of the reflected wave or add a significant noise temperature. The beam is generated with a hollow cathode configuration in a new plasma mode which has been called the enhanced glow. Recent theoretical work has shed light on the beam produced plasma, the cathode, and the potential application to a radar system[5-7].

The most difficult aspect of the agile mirror project so far has been agility. This involves both pulsing additional magnetic fields, and designating an emitting region of the cathode. Each of these must be done on the ten to one hundred microsecond time scale, and neither has been demonstrated yet. Accordingly, it is natural to ask whether the agile mirror plasma has other applications to microwave systems which do not require agility. We show here that the agile mirror plasma has the potential to provide fast, high power microwave switching. This is a capability which generally does not exist at present, and it could have important applications. For a radar system, such applications include pulse to pulse polarization agility, and pulse to pulse electronic control of an antenna gain. It also gives rise to a new approach to high power microwave and millimeter wave circulators. There are undoubtedly other applications as well, but we will focus on these and will also concentrate on frequencies at X-Band and above, up to millimeter waves.

The main attribute of the plasma which allows electronic control and switching is the fact that the plasma can either reflect microwaves, or give a phase shift to transiting microwaves. Furthermore this phase shift may be electronically controlled. Although the ability of plasmas to shift the phase of a microwave signal has long been known, the ability to produce dense plasmas efficiently, rapidly and quietly by exploiting the enhanced glow mode of operation is new. Section 2 discusses the plasma as a phase shifting medium and works out various attributes and limits to this behavior. Section 3 discusses the application of these phase shifters and reflectors to waveguide systems, and Section 4 discusses the same for quasi-optical (i.e. beam waveguide) systems.

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2. The Plasma as a Phase Shifter

In this section we discuss various aspects of the plasma as a phase shifter in a pulsed microwave system. We assume that the time between the pulses is long enough that the plasma may be pulsed on or off during that time. Thus we require a gas which is fairly easy to breakdown, and also one which recombines quickly when the beam is turned off. For the latter the gas should be a molecular gas such as air. For the examples here we generally consider, air, nitrogen or oxygen. For the enhanced glow agile mirror plasma for X band microwaves, the turn on and turn off times are typically tens of microseconds.

A The Phase Shift.

In a collisionless plasma with plasma frequency ω_p, the wave number is given by

$$k = [\omega^2 - \omega_p^2]^{1/2}/c \tag{1}$$

Thus the phase change in propagating across the plasma of length L, as opposed to propagating this distance in vacuum is

$$\Delta\phi = (\omega L/c)\{[1 - (\omega_p^2/\omega^2)]^{1/2} - 1\} \approx -0.5(\omega L/c)\,\omega_p^2/\omega^2 \tag{2}$$

where the last approximation in Eq. (2) is for $\omega_p^2 << \omega^2$. The phase shift then is proportional to the plasma density. Since this density is controlled by the circuit parameters creating the plasma, typically the voltage and current, the phase shift can be controlled electronically. There are undoubtedly applications for a phase shift which can be continuously and rapidly varied at high power. However we focus here principally on a phase shift of π, that is a phase shift which changes the sign of the microwave field. For X band (10 GHz) and W band (100 GHz), this gives the approximate relation for plasma density

$$nL(\mathrm{cm}^{-2}) \approx 3\times10^{12}\ (10\ \mathrm{Ghz}) \quad \text{or} \quad nL(\mathrm{cm}^{-2}) \approx 3\times10^{13}\ (100\ \mathrm{GHz}) \tag{3}$$

where n is the electron density in cm^{-3} and L is in cm. The densities and lengths implied by Eqs. (3) are consistent with what has been demonstrated in the agile mirror plasma.

B. The Attenuation

The plasma not only gives rise to a phase shift, it also attenuates the microwave signal transiting it, and naturally this attenuation must be small for the switch to be useful. If the plasma is collisional, the dispersion relation is given by

$$[kc/\omega]^2 = 1 - \omega_p^2/\omega(\omega + i\nu) \tag{4}$$

where ν is the collision frequency. The imaginary part of k, which gives rise to attenuation, is

$$k_i \approx \nu\omega_p^2/2c\,\omega^2 \qquad (5)$$

in the low collision frequency limit. If we assume that the phase shift is equal to π, then we find that the total power attenuation is given by

$$\Delta P = P\,\exp\text{-}(2\pi\nu/\omega) \qquad (6)$$

The collision frequency is given by $N\sigma v$ where N is the background neutral density, σ is the momentum exchange collision cross section, and v is the electron thermal velocity. Assuming that $N \approx 3\text{x}10^{15}\ \text{cm}^{-3}$, $\sigma \approx 2\text{x}10^{-15}\ \text{cm}^2$, $v \approx 4\text{x}10^7\ \text{cm}^{-3}$, we find that the power is reduced by about 2% upon transiting the plasma. It is worth pointing out, that the beam generated plasmas produced in the NRL agile mirror have temperature $\approx$ 1 ev.

C. The Added Noise

One difficulty in using plasma components has been that they are often noisy. However the enhanced glow plasma is relatively quiet; measured noise temperatures are varying from a few hundred to a thousand degrees. For a thermal equilibrium plasma, it is not difficult to calculate the noise temperature of the plasma as an emitter. To do so, use the standard equation for radiation temperature of a substance in thermal equilibrium

$$T_r = \int_0^L ds\ T_p(s)k_i(s)\ \exp -\tau(s) \qquad (7)$$

where k_i is the damping coefficient and $\tau(s) = \int_0^s ds'\ k_i(s')$, is the opacity between s and the edge of the plasma at s=0, and T_p is the plasma temperature. (The other edge of the plasma is at s=L.) As we have seen , the damping coefficient is given by Eq.(5), so in the limit of small damping,

$$T_r = T_p\ L\nu\omega_p^2/2c\ \omega^2 = T_p 2\pi\nu/\omega \qquad (8)$$

where for the last equality in Eq. (8) we have used the fact that L is such as to give a phase shift of π. Thus for a 1 ev thermal equilibrium plasma, the added noise is about 200°K for a plasma like air.

However the plasma is not in thermal equilibrium because there is an electron beam in it. This can give rise to electrostatic noise at the plasma frequency, and this noise can give rise to enhanced radiation at ω_p and $2\omega_p$. The enhanced glow hollow cathode generates a beam with a fairly large spread in parallel velocity. The plasma

waves are driven unstable by the beam, but are damped by collisions with the background neutrals. Assuming that the beam has a Maxwellian distribution with thermal velocity Δv_b, then the condition for stability is[7]

$$\nu/\omega_p > [v_b / \Delta v_b]^2 (n_b/n) \qquad (9)$$

where n_b is the beam density and v_b is the mean beam velocity. Even if the plasma is stable, there is still the question of non thermal emission of plasma waves by the beam. However this is mostly at frequency ω_p and $2\omega_p$, so that as long as the microwave frequency is greater than either of these frequencies, the noise should not be excessive. We plan to examine this in future work. Recent noise temperature measurments on the agile mirror plasma have shown that for frequency above the plasma frequency (by typically 20%), the plasma is very quiet. The received noise with or without the plasma is about the same. However closer to the plasma frequency, the situation is more complicated. Some measurements have shown noise temperature of several hundred degrees, others of several thousand.[8]

D. Maximum Power Capability

There are two things that may limit the power that the plasma can handle. The first is that the transiting microwave power must be sufficiently low that it does not itself cause breakdown, and secondly, it must not cause parametric instabilities either. The former is rather simple to estimate, because the microwave field necessary for breakdown can be related to the DC breakdown field. The DC breakdown field is the field which causes the electron heating necessary for breakdown, and it is proportional to N, the gas density. A typical of breakdown strength for most gases is, $E/N \approx 10^{-15}$ Volt cm^2. The microwave field which causes the same plasma heating is given by

$$[\nu^2/(\nu^2 + \omega^2)] E_\mu{}^2 = E_{DC}{}^2 \qquad (10)$$

where E is the rms field. For the agile mirror plasma, where $\omega >> \nu$, the maximum microwave field is given roughly by

$$E_\mu \approx (\omega/\nu) E_{DC} \approx (\omega/\sigma v_e) \times 10^{-15} \text{ V/cm}, \qquad (11)$$

where v_e is the electron thermal velocity. Since the DC breakdown field is proportional to N and so is ν, the microwave field is independent of N in the high frequency limit. For an X band microwave signal, and a typical momentum exchange cross section of 2×10^{-15} cm^2 and a 1 ev plasma, we find the maximum power density is somewhere around 2 kilowatts per cm^2. For the millimeter wave, 100 Ghz case, the maximum power density is about 2 orders of magnitude higher.

Let us now consider parametric instabilities. These are usually described in terms of the oscillating electron velocity in the microwave field. This oscillating velocity is given by

$$v_{os}(\text{cm/sec}) = 2.6\times10^5 \lambda \sqrt{I} \qquad (12)$$

where λ is the incident microwave wavelength in cm, and I is the irradiance in W/cm^2. There are several possible instabilities. However since the plasma density is below the critical density at the microwave frequency, the conventional decay and oscillating two stream instability are not present. The most dangerous parametric instabilities that can occur in an underdense plasma are then the stimulated Raman and Brillouin backscatter instabilities[9]. We will consider each of these.

The stimulated Raman instability is the decay of the incident wave into a backscattered photon with frequency $\omega - \omega_p$ and plasma oscillation at frequency ω_p. Since both the electron plasma wave and the backscattered wave damp by electron neutral collisions, the irradiance must be above some minimum value for instability to occur. Equation (7.28) of Ref. 9 gives the threshold as

$$(v_{os}/c)^2 > (\omega_p/\omega)^2 (v^2/\omega\omega_p) \qquad (13)$$

If the plasma density is 20% of the critical density, and the collision frequency is about 0.001 times the frequency, we find that the maximum irradiance before stimulated Raman backscatter can occur is about 300 W/cm^2 for the X-band case.

The stimulated Brillouin backscatter instability occurs when the incident microwave power decays into a backscattered wave and an ion acoustic wave. If the ion acoustic wave exists, Kruer[9] points out that the threshold for instability is very low. Fortunately, for the application we envision here, the ion acoustic wave does not exist as an undamped or nearly undamped wave. For most gases, the resonant charge exchange cross section for ions (N_2) is very large, typically about 2×10^{-14} cm^2 at the low ion energies we consider[10]. Thus the ion collision frequency, $Nv_i\sigma_x$ is about 3×10^6 sec^{-1} assuming $N = 3\times10^{15}$ and $v_i = 5\times10^4$cm/s. For the X-band case, the wave number of the ion perturbation is twice the wave number of incident microwaves, or about 4 cm^{-1}. Thus the ion momentum exchange collision frequency is about 10 times large than the ion acoustic frequency.

To investigate the stimulated Brillouin backscatter instability in this case, we use the general dispersion relation for parametric instabilities in unmagnetized plasmas[11,12],

$$1 + \varepsilon_e + \varepsilon_i = -\kappa^2 v_{os}^2 \varepsilon_e \varepsilon_i / [(\omega-\Omega)^2 - (k-\kappa)^2 c^2 - \omega_p^2(1 + iv_e/\omega)] \qquad (14)$$

where (Ω,κ) are the frequency and wave number of the low frequency perturbations set up, and the ε's are the dielectric constants of the electrons and ions and the collision frequency now takes on an index e to denote the electron collision frequency. For the

case of backscatter, $\kappa = 2k$, and Ω for the ion perturbation is very small compared to the microwave frequency ω. For the case of a very low frequency perturbation,

$$\varepsilon_e = \omega_{pe}^2/\kappa^2 v_e^2 \quad \text{and} \quad \varepsilon_i = -\omega_{pi}^2/i\Omega\nu_x \qquad (15)$$

where now the plasma frequencies take an index for electrons or ions. Using these expressions, the dispersion relation for the stimulated Brillouin backscatter can be manipulated into the form

$$\Omega^2 + i[(4\omega^2 v_e^2 m/M\nu_x c^2) + (\omega_{pe}^2 \nu_e/2\omega^2)]\,\Omega - 2\,v_e^2\,\nu_e\,\omega_{pi}^2/c^2\nu_x + 2i\,(\omega_{pi}^2\omega/\nu_x)\,(v_{os}/c)^2 = 0 \qquad (16)$$

The terms in the square brackets denote the damping of the backscattered photon and the ion perturbation. Each is stabilizing, although for the parameters we have been using, the electron term is considerably more important. Then we find that the plasma is stable to stimulated Brillouin backscatter if

$$\omega_{pe}^2 \nu_e/4\omega^2 > (\omega/\nu_x)^{1/2}\,\omega_{pi}\,(v_{os}/c) \qquad (17)$$

For the parameters we have been considering, this implies an irradiance of a few hundred W/cm^2 for the incident microwave power.

To conclude, we have calculated threshold microwave irradiances for microwave plasma generation and the most obvious parametric instabilities. For our canonical parameters, the threshold irradiance ranges from a few hundred W/cm^2 to a kilowatt/cm^2 at X-Band for a typical agile mirror plasma. Since a fundamental mode X-Band wave guide has an area of about three cm^2, the maximum total power is about a kilowatt if we stay in fundamental mode waveguide. Thus at X band, if it is required to switch larger power, the microwaves must be taken out of the fundamental mode guide, and be allowed to spread out to larger area, perhaps an oversized or beam waveguide. For the 100 GHz example, we envision beam waveguide at the outset, and the threshold irradiances are generally higher as well. Thus for millimeter wave systems in a beam waveguide, the threshold power is almost certainly larger than the system power.

E. Microwave Reflection from the Plasma

In addition to phase shift and absorption, the microwave power is also reflected from the plasma. Imagine that the microwave in free space has propagation constant k_o and in the plasma has propagation constant k. The power reflection coefficient from a plasma slab of length L is[13]

$$R^2 = \{4r^2\sin^2 kL\}/\{[1-r^2]^2 + 4r^2\sin^2 kL\} \qquad (18)$$

where r is the reflection coefficient from a single surface, $r = \{[k_o-k]/ [k_o+k_o]\}$. Equation (18) shows that the reflection may be minimized in one of two ways. First of all, one eliminate reflection by usingwith a plasma whose length is an integral number of half wavelengths so that

$$kL = p\pi \qquad (19)$$

which is the standard condition for vacuum windows for microwave systems. Assuming that the phase difference between the path with the plasma and the path without it is π, the first few p values give relative plasma densities as given below

p	ω_p^2/ω^2	
1	3/4	
2	5/9	(20)
large	1/2p	

Thus the density decreases as p increases, but rather slowly. Also, at large p, the bandwidth of the slab as a zero reflector decreases.

An alternative is to work at lower plasma density and make use of the fact that the maximum reflection, as given by Eq. (18) is low. For instance at one third critical density, the maximum reflected power is only about 4%, and at one fifth critical, it is about 1%.

There are other approaches to minimizing reflection as well. For instance if the density profile of the plasma is gentle (compared to a wavelength) rather than sharp, the reflection is minimized. Also in a waveguide system, there are all sorts of stubs and shunts that are used to minimize reflection. The reflection coefficient depends on the phase change as the microwaves transit the stub. By using plasma in the stub as well, this phase can be controlled electronically. There are chapters of books[14], and undoubtedly whole books dedicated to this subject and we will not pursue it further here. For quasi-optical systems, there are undoubtedly analogous approaches. In any case, it does not seem that reflection from the plasma is a significant obstacle to the application of plasma phase shifters in high power microwave switches.

3. The Plasma Switch in Waveguide Systems

We consider here two types of waveguide switches using agile mirror plasmas, and then we discuss possible applications to a radar system. The first we call a rail switch and it is sketched in Fig. (1). In this case the plasma does not act as a phase shifter, but rather as a portion of the waveguide wall, i.e. as a reflector. The density must be sufficiently high that the plasma acts as a waveguide wall. In the rail switch

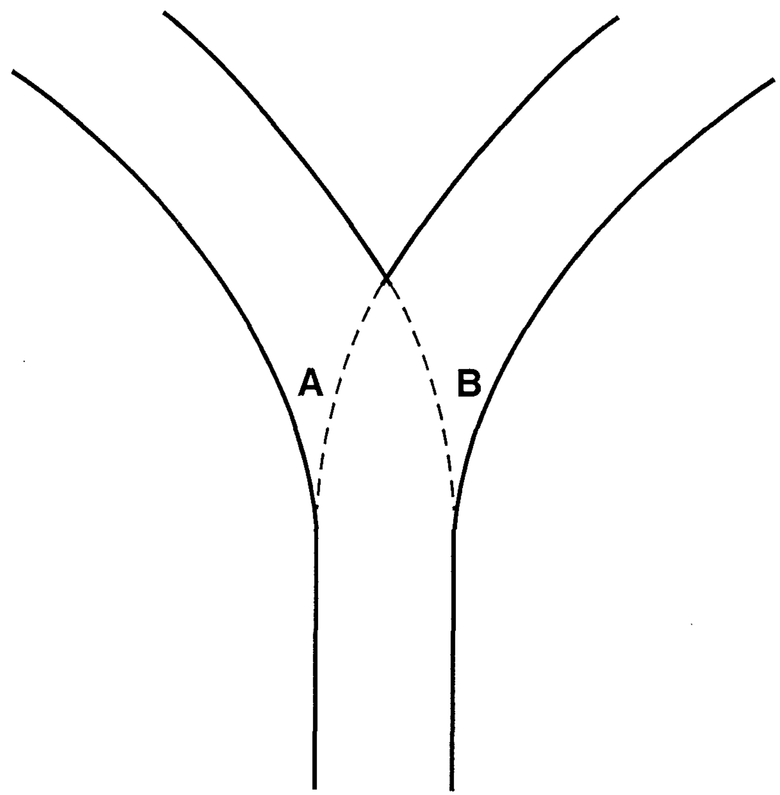

Fig. 1 - The Rail Switch. The dotted lines are possible plasma positions.

configuration shown in Fig. (1), there are two possible waveguide walls which might be plasma. When the plasma is formed on the dotted path labeled A, the wave switches to the right, and when it forms on the dotted path labeled B, the wave switches to the left. Since the microwave only reflects from the plasma and does not propagate through it, conditions for plasma noise and parametric instability are almost certainly relaxed from what was derived in the last section, at least if the plasma has a sharp density transition.

We now consider another type of switch where the microwaves propagate through the plasma as discussed in Section 2. There are most likely many different types of waveguide switch, and we will consider one which uses a magic T. A magic T is shown in Fig (2A). If the portion from waveguide 2 to waveguide 3 is considered as the main, fundamental mode waveguide, then the waveguide labeled 1 forms an H plane T, and the waveguide labeled 4 forms an E plane T. It is possible to match all four arms of the T, so the 4x4 scattering matrix is

$$\sqrt{2}S = \begin{bmatrix} 0 & 1 & 1 & 0 \\ 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & -1 \\ 0 & 1 & -1 & 0 \end{bmatrix}$$

The symmetry decouples arms 1 and 4, and symmetry and orthogonality relations of the scattering matrix, plus the fact that all arms are matched dictates that the matrix must have the above form[15].

Notice that if two signals enter the T from arms 2 and 3, the signal going out arm 1 is proportional to the sum and the signal going out arm 4 is proportional to the difference. The high power waveguide switch is then shown in Fig. (2B). The signal is incident into a matched waveguide T (i.e. a 3 db coupler) and proceeds along the two legs labeled α and β. These are incident upon legs 2 and 3 of the magic T. In (for instance) leg α is the plasma which can be turned on or off. When the plasma is off, the lengths of the two legs α and β are the same, so the power exits the magic T on the sum channel, waveguide 1. However when the plasma is turned on, there is an additional phase shift of π in leg α, so the power exits the magic T through the difference channel, waveguide 1. If most of the time only one of the legs of the magic T is used, this switch has an advantage over the rail switch because for most of the microwave pulses, the plasma would not have to be turned on.

Now let us a consider some applications of the high power switch to a radar system. One possible application is polarization agility. By twisting a waveguide, the polarization of the microwave may be altered. Thus the high power microwave switch we have developed may give a radar system pulse to pulse polarization agility, a capability that radar systems do not generally possess today.

Another application is discrete electronic gain control of a radar antenna. If a radar has a dish of diameter D, and the feed horn illuminated the entire dish, the gain G is

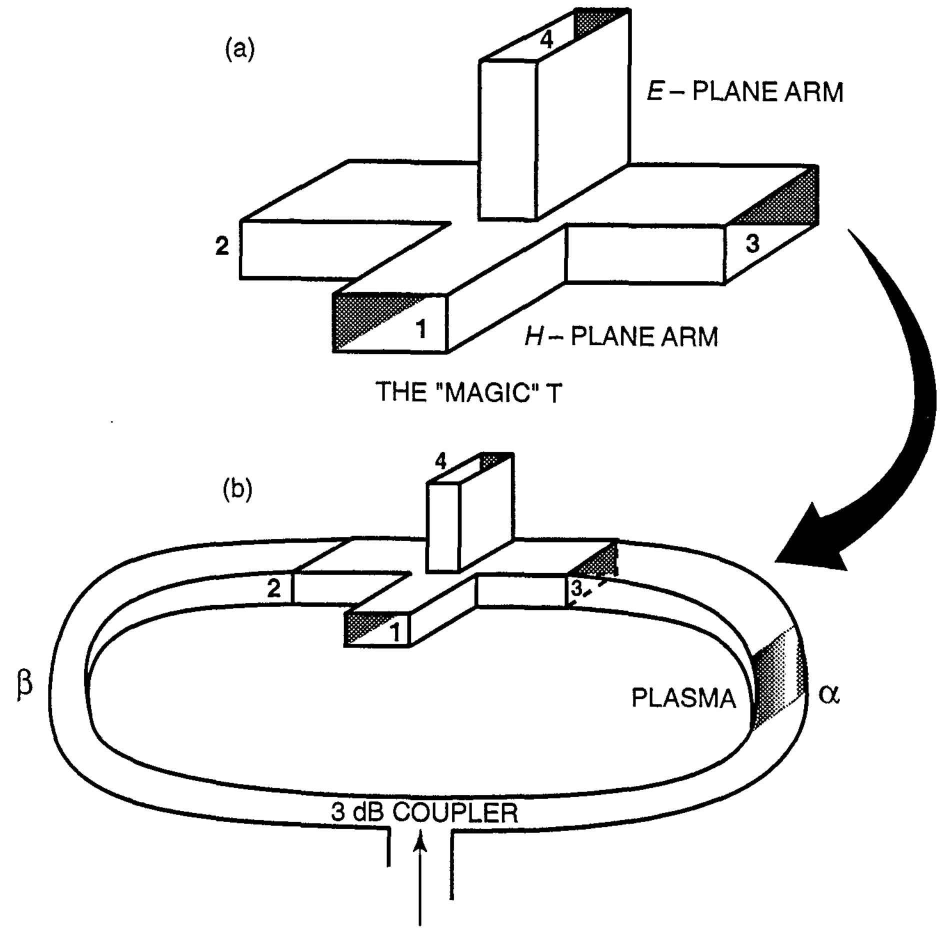

Fig. 2 - A high power waveguide switch with a pulsed plasma and magic T.

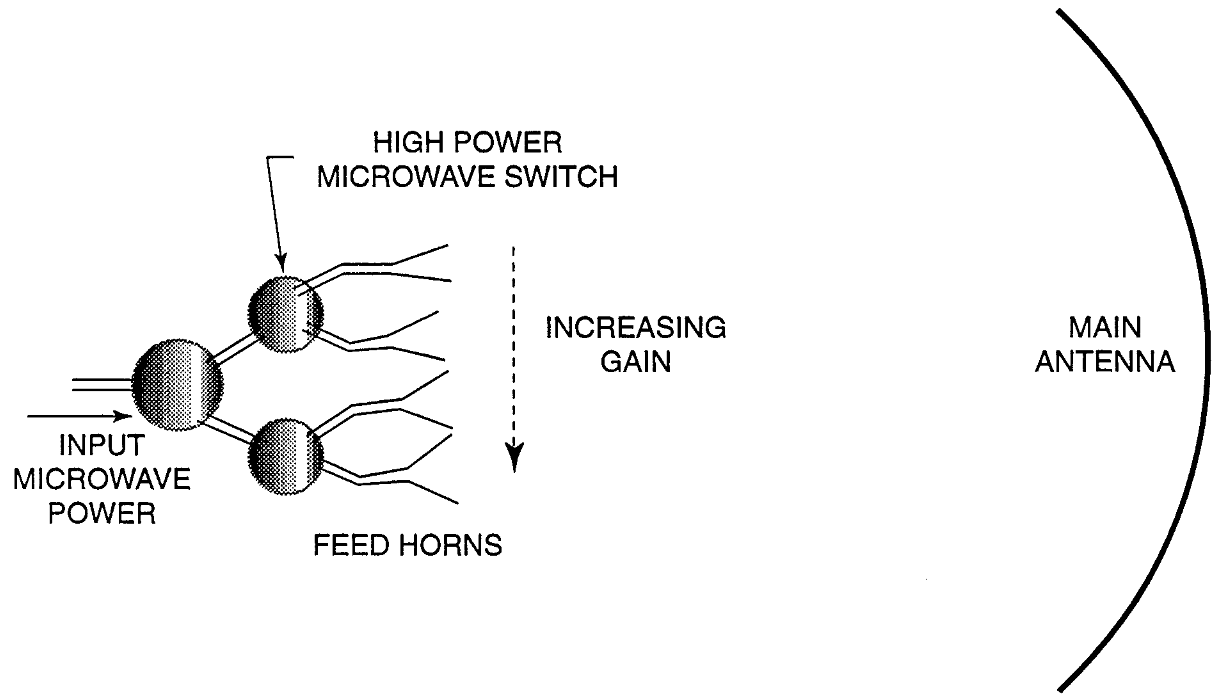

Fig. 3 - A single antenna with four discrete antenna gains that can be electronically selected pulse-to-pulse.

π^2D^2/λ^2 where λ is the wavelength. The angle of the radiation beam is roughly λ/D radians. If a radar is searching for a target, it has to cover some volume of space. If the gain is lower, it can search this volume more quickly. Once it finds what might be a target, it would then be advantageous to raise the gain so as to examine it more carefully and/or track it. The high power microwave switch we have discussed here gives a capability to electronically alter the gain among several channels. By cascading say 3 of these switches, one could distribute the power into one of four waveguides. These waveguides would end in 4 feed horns , which illuminate different parts of the antenna. One horn would illuminate all of the antenna in the conventional way, and in this channel, the gain would be the maximum gain of the antenna. As the horns illuminated smaller and smaller regions of the antenna (i.e. smaller D's), the gain of the antenna would decrease and the angular pattern would broaden. This is illustrated in Fig. (3).

4. The Plasma Switch in Quasi-Optical Systems

As the frequency increases, fundamental mode waveguides become smaller and smaller, have greater losses and less power handling capability. To counteract this tendency, at higher frequencies, and sometimes as low as X-Band, beam waveguides, are used. These employ Gaussian beams in free space, which are periodically refocused with lenses and/or mirrors. Because they are Guassian beams, they are often also called quasi-optical systems. Lincoln Laboratory[14,15] has developed a number of components for its 35 and 94 GHz missile tracking radars based on Kwajelein. It is also working to develop similar components for the NRL 94 GHz radar. This radar is based on a gyroklystron transmitter, and is expected to have a peak power of 100 kW and an average power of 10 kW. This represents a large jump in millimeter radar capability. As such, the availability of high power components is an important concern. The plasma components, where microwaves are both reflected from and transmitted through the plasma could play a key role for both high power extension of existing components and the development of new components.

A crucial concern in the NRL radar is the circulator which does not exist now at high power. One potential design has been developed at Lincoln Lab, but there are a number of ways the pulsed plasma could be used instead. Usually a circulator is a passive device, whose non-reciprocal nature is due to its magnetic field. However there is no reason why it cannot be a powered device as long as the power to it is small compared to the transmitter power. This is certainly the case for the NRL agile mirror plasma coupled to the NRL 94 GHz 100kW gyroklystron powered radar. A simple circulator based on reflection is shown in Fig. (4). Since the radar duty cycle is low, typically 1-10%, the plasma mirror is turned on only when the transmitter is on; when the transmitter is off, the received millimeter wave path is determined by passive optical and microwave components. In Fig. (4), a plasma mirror deflects the transmitted power to the beam path. The received power, in the absence of the plasma, takes a different path.

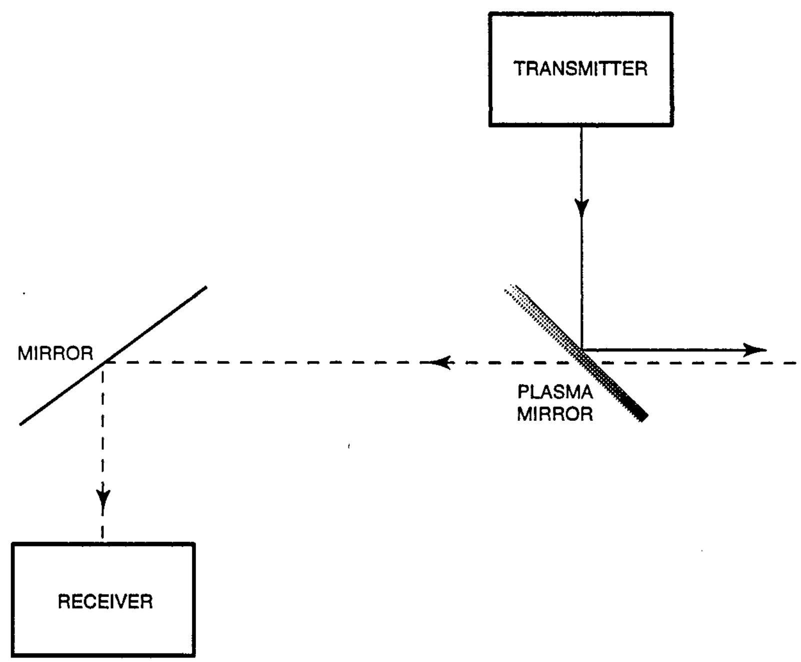

Fig. 4 - A quasi-optical, millimeter wave "circulator" based on the plasma mirror.

A particularly appealing concept for a reflector for a 94 GHz system is a glancing angle mirror. As the frequency of the microwave signal increases, the critical electron density for normal incidence also increases, to about 10^{14} cm^{-3} for 94 GHz. However at glancing incidence, the critical density decreases as the $\cos^2\theta$ where θ is the angle from the perpendicular. Thus at a glancing angle of 0.1 radian, the effective critical density is only 10^{12} cm^{-3}. Of course at glancing incidence, a longer plasma is needed. For instance if the quasi-optical beam has a diameter of 6 cm, at a 0.1 radian grazing incidence, the mirror would need to be 60 cm long (but only 6 cm wide). Since the NRL agile mirror experiment has already demonstrated the production of a sheet plasma square 60 cm on a side with density 10^{12} cm^{-3}, the basic physics of a high power glancing incidence 94 GHz plasma switch has effectively already been demonstrated.

Another capability that the plasma could provide is polarization agility as in the case of the waveguide system. This is demonstrated in Fig. (5). In Fig. (5A), a millimeter wave with vertical polarization (in the x direction) is incident on a wire grid mirror tilted at 45°, to the direction of incidence. The wires in the mirror are themselves tilted at 45° to the x axis in the plane of polarization. Thus if the polarization vector is decomposed into two components, one normal to the wire grid and one parallel to it, the two components will have equal amplitude. The former will pass through the mirror as if it were not there, and the latter will be completely reflected. Thus the incident beam will split into two components, with two orthogonal polarizations, each 45° to the incident polarization. In the small circles in Fig. (5A) are shown the directions of polarization of the millimeter waves in the plane transverse to the wave vector. The deflected wave is bounced off of two normal mirrors and then is returned to the original wave path by reflecting from another wire mesh mirror. The non deflected wave will simply pass unhindered through both wire mesh mirrors. If both paths have the same optical length, the wave will reconstruct in its original vertical polarization, as shown.

Now envision that the top path, now shown in Fig. (5B), has a plasma which gives a relative phase shift of π. In this case, the two waves reconstruct at the second mirror as shown. Notice that the polarization is rotated by 90°. Thus by pulsing the plasma on or off from pulse to pulse, it is possible to obtain polarization agility. This appears to be a new capability for a high power millimeter wave radar.

It is also possible to use this polarization agility to make an active circulator. Let us imagine that the millimeter wave comes out of the transmitter polarized vertically, and in front of the first wire grid mirror in say Fig.(5B) there is another wire grid mirror, whose normal is at 45° to the wave vector, but whose wires are oriented horizontally. The incident wave will pass through this unhindered. Then in the rest of the configuration of Fig. (5B), it will have its polarization rotated to horizontal. As long as the target does not give significant depolarization of the scattered signal, it will return horizontally polarized as well. The plasma for the return pulse is now off, (the configuration of Fig. (5A)) so the polarization remains horizontal. However now it is reflected by the original wire grid reflector which had its wires oriented horizontally. This reflected power will go into the receiver, with perhaps a small part of the received power (the depolarized part) going harmlessly into the transmitter. Thus, the presence of

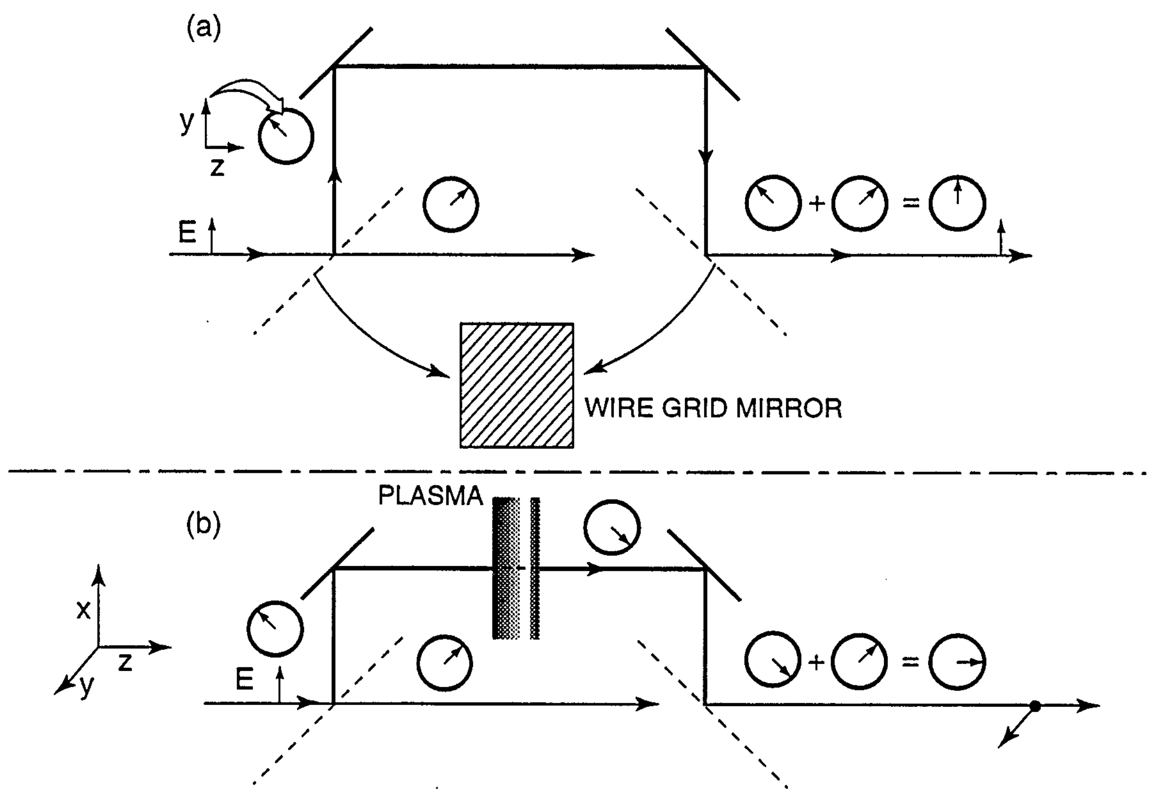

Fig. 5 - Plasma generated polarization agility in a beam waveguide.

the pulsed plasma, either as a reflector or a phase shifter can give rise to an innovative approach to the problem of constructing a high power circulator for millimeter waves.

Finally the plasma could also allow for electronic control of antenna gain just as in the case of the waveguide system. Using the plasma as a fast, high power switch in any of the beam waveguide configurations discussed, the microwave power could be switched to one of several different beam waveguide feeds which then illuminate different parts of the main antenna, providing for different antenna gain. It is also possible that the plasma could give pulsed continuous gain control in an antenna by shaping the plasma into a convex or concave lens by appropriately tailoring the magnetic field. Then the focal length could be electronically controlled by controlling the plasma electron density with the voltage and current of the discharge.

5. Conclusions

One principal accomplishment of the NRL agile mirror program has been to exploit a new plasma regime, the enhanced glow. This efficiently and quickly produces a very high quality a planar plasma. If agility could be demonstrated, it could give rise to important new capabilities for radar system. However this plasma, even without agility seems to have the capability of developing into important new components for high power microwave systems.

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